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COVER SHEET FOR TECHNICAL MEMORANDUM

TITLE- AS-502 Entry Accuracy

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DATE- March 28, 1968

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FILING SUBJECT(S)- Entry, AS-502
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ABSTRACT

This memorandum is a study of terminal miss for Mission AS-502 as a function of initial flight-path angle, velocity, lift-to-drag ratio, target range and initial cross-range displacement. Nominal values of these parameters for AS-502 are: -6.5°, 36,500. fps, 0.335, 2500. N.M., and 0. N.M., respectively.

It was found that L/D's of 0.320 and above resulted in negligible terminal misses for all flight-path angles between -5.80° and -7.05° and ranges up to 2800. N.M. For an L/D of 0.304, ranges above 2400. N.M. resulted in significant misses (or holes) within the nominally acceptable region. Increasing the initial cross-range displacement resulted, not in removing the holes, but displacing them in the corridor. For the 2500. N.M. range an increase in initial velocity reduced the number and magnitudes of the misses for all L/D's studied.

Thus AS-502 entry targeting is acceptable for nominal conditions, but low L/D may cause a miss of the order of 50. N.M.

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1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: AS-502 Entry Accuracy
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DATE: March 28, 1968

FROM: I. Bogner
S. B. Watson

TECHNICAL MEMORANDUM

The entry profile for AS-502, originally the same as that of AS-501, is being retargeted in order to subject the heat shield to a more severe thermal test. The change, discussed in References 1, 2, and 3, results in the following nominal entry initial conditions:

Inertial reentry velocity	36,500. fps
Inertial reentry flight-path angle	-6.5°
Reentry range	2500. N.M.
Lift-to-drag ratio (pre-flight estimate)	0.335

The decision to select the above initial conditions was based in large part on data presented in Reference 3. In it the following parameters were studied to determine their effect on final target miss:

Initial flight-path angle, γ :	$-5.6° < \gamma \leq 7.0°$
Initial velocity, V :	36,000., 36,500., 37,000. fps
Lift-to-drag ratio, L/D* :	0.304, 0.345, 0.410
Range to target, R :	3000., 2500. N.M.

It is the purpose of this memorandum to present the results of an expanded study of the same general problem, i.e., target miss as a function of γ, V, L/D and R. Numerous simulations based on the above parameters were run by the authors of this memorandum in order to compare results with those presented in Reference 3. Reference 3 used a grid of

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*L/D = 0.304 is based on the nominal 0.335, less the 3 σ tolerance (0.028) after weighing, less the effect of fuel usage during the initial part of entry causing a cg shift (0.003).

0.1° in γ, while the data presented here is based on a 0.01° step size. As a result, one finds that more misses appear, which supplement those noted in Reference 3. It is, nevertheless, our judgment that the results are qualitatively similar to those in Reference 3. Differences that exist are in magnitude of miss or in the precise location of the γ's where the misses occur.

Figures 1 through 3 present the terminal miss data for an L/D of 0.304. The figures are as follows:

COORDINATES: γ vs Final Miss for L/D = 0.304.

Figure 1 : $V = V_{nominal}$ = 36,500. fps

Graph 1 : R = 3000. N.M.

Graph 2 : R = 2500. N.M.

Figure 2 : R = 2500. N.M.

Graph 1 : $V = (V_{nominal} - 200.)$ fps

Graph 2 : $V = (V_{nominal} + 200.)$ fps

Figure 3 : R = 3000. N.M.

Graph 1 : $V = V_{nominal}$ = 36,500. fps

Graph 2 : $V = (V_{nominal} + 200.)$ fps

Figure 1 indicates two items worthy of note: For the fixed parameters indicated (i.e. L/D, V, R), the longer range results in significantly larger holes* of greater miss than does the shorter range. Key items are the holes at γ's of -6.48° and the holes below γ's of 7.0° for the 2500. N.M. range. Note that -6.48° is close to the new targeted value for AS-502. Figure 2 indicates that the hole problem for the short range is reduced as the initial velocity is increased. Figure 3 demonstrates that this is not true for the longer range. Here the holes have shifted but there are no significant reductions.

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*A hole may be viewed as a region within the normal range of γ for which the miss exceeds the Apollo Program Specification value.

A suggested method of reducing the number of holes is to put the target slightly out of plane. Figures 4 and 5 are presented to explore this.

Conditions: L/D = 0.304, V = 36,500. fps, R = 2500. N.M.

Figure 4. Coordinates: Initial Cross-Range Displacement vs Final Miss

Graph 1: γ = -6.48°

Graph 2: γ = -7.0°

Graph 3: γ = -7.02°

Graph 4: γ = -7.04°

Figure 5. Coordinates: γ vs Final Miss for Initial Azimuth Offset from 80.806° (nominal) to 81.1°. This increases the initial cross-range miss from -8. to -20. N.M.

Figure 4 illustrates that increasing the initial azimuth, in order to put the target out of plane, does indeed reduce the misses for the γ's shown. Note that changing the initial lateral miss from -8. N.M. to -20. N.M. at γ = -6.48° reduces the final down-range miss from 40. N.M. to less than 2. N.M. The new initial azimuth is used in Figure 5, where again γ is plotted against the final miss. The graph shows that the hole is simply shifted to a slightly different γ.

Thus far, the data presented has been concerned with the lowest L/D, 0.304. Figure 6 compares the L/D's as follows:

Conditions: γ = 6.5°, V = $V_{nominal}$ = 36,500. fps

Coordinates: Range vs Miss

Graph 1: L/D = 0.304

Graph 2: L/D = 0.32

Graph 3: L/D = 0.335

The data indicates that for a given L/D misses occur at longer ranges. One can also state that increasing the L/D above the minimum of 0.304 reduces the miss problem in the range (2500. N.M.) of interest.

Consider now the higher L/D's of 0.335, 0.345 and 0.410. Simulations based upon the 0.410 L/D indicated no holes over the range of γ's from -5.8° to -7.0° for both the 2500. N.M. range and 3000. N.M. range and hence no graphs are presented. Data for the other L/D's are presented first in Figures 7 and 8.

Coordinates: γ vs Final Miss

Figure 7: L/D = 0.345, $V = V_{nominal}$ = 36,500. fps

Graph 1: R = 3000. N.M.

Graph 2: R = 2500. N.M.

Figure 8: L/D = 0.335, $V = V_{nominal}$ = 36,500. fps

R = 3000. N.M.

Figure 7 supports the earlier indications that holes are reduced by reducing range. Figure 8 when compared with the data in Figure 9 also supports this. Figure 7 and 9, taken together, indicated that for the 2500. N.M. range and nominal velocity, either L/D prevents holes of any significance. On the other hand, note the hole at approximately -6.5° for the longer ranges.

Figures 9, 10 and 11 contain the data for L/D's at and near nominal on the low side, for the lower range, with velocity as the parameter.

Coordinates: γ vs Final Miss

Figure 9: L/D = 0.335, R = 2500. N.M.

Graph 1: V = 36,300. fps

Graph 2: V = 36,500. fps

Graph 3: V = 36,700. fps

Figure 10: L/D = 0.330, R = 2500. N.M.

Graph 1: V = 36,300. fps

Graph 2: V = 36,500. fps

Graph 3: V = 36,700. fps

Figure 11: L/D = 0.320, R = 2500. N.M.

Graph 1: γ = 36,300. fps

Graph 2: γ = 36,500. fps

Graph 3: γ = 36,700. fps

The three figures demonstrate that misses are negligible for the three L/D's and the velocities indicated. The price to be paid for increasing the range is indicated in Figure 6.

Summary and Conclusions

Bellcomm strongly recommended for AS-501 a 2000. N.M. range instead of 2500. N.M. The difference was that the AS-501 initial flight-path angle was at the steep end, -7.13° - an area where holes were known to exist. Figure 12 illustrates a hole at -7.14° for AS-5ol initial conditions. At the time prior to AS-501, more extensive parametric studies produced data to point up the possibility of a miss.

The entry guidance used in AS-501 and AS-502 has been revised for use in later missions. Holes of the type thus far encountered should not appear in missions using updated guidance.

In summary, the following conclusions are noted:

1. The retargeted entry of

   $$V = 36{,}500.\ \text{fps}$$
   $$\gamma = -6.5°$$
   $$R = 2500.\ \text{N.M.}$$

   is acceptable for the nominal L/D of 0.335 and for L/D's as low as 0.320. At an L/D of 0.304, the targeted γ of 6.5° is very close to the hole at -6.48°.

2. If the L/D falls as low as 0.304, misses can be expected for ranges above 2400. N.M.

3. Based on the data of Figure 6, the maximum range should be 2800. N.M.

4. The touchdown target should be updated if the predicted range exceeds 2800. N.M.

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Attachments

REFERENCES

1. Updated Profile for AS-502, V. S. Mummert, January 16, 1968. A two-page memorandum noting the changes in the mission profile plus appendices consisting of References 2 and 3.

2. Retargeting of SPS-1 and SPS-2 for AS-502/020, Mission A-2, Apollo 6, Mission A-2/020, Carl R. Huss, MPAD/MSC, January 9, 1968. A one-page memorandum discussing the changes in mission profile as they affect entry.

3. A-2/CSM 020 (Apollo 6) Retargeting Briefing (A-152), R. H. Manders, TRW, December 18, 1967. A summary sheet plus thirteen viewgraphs concerned with the parametric study of the various aspects of the entry, including the effects on misses of entry interface flight-path angle, L/D, and entry interface velocity.

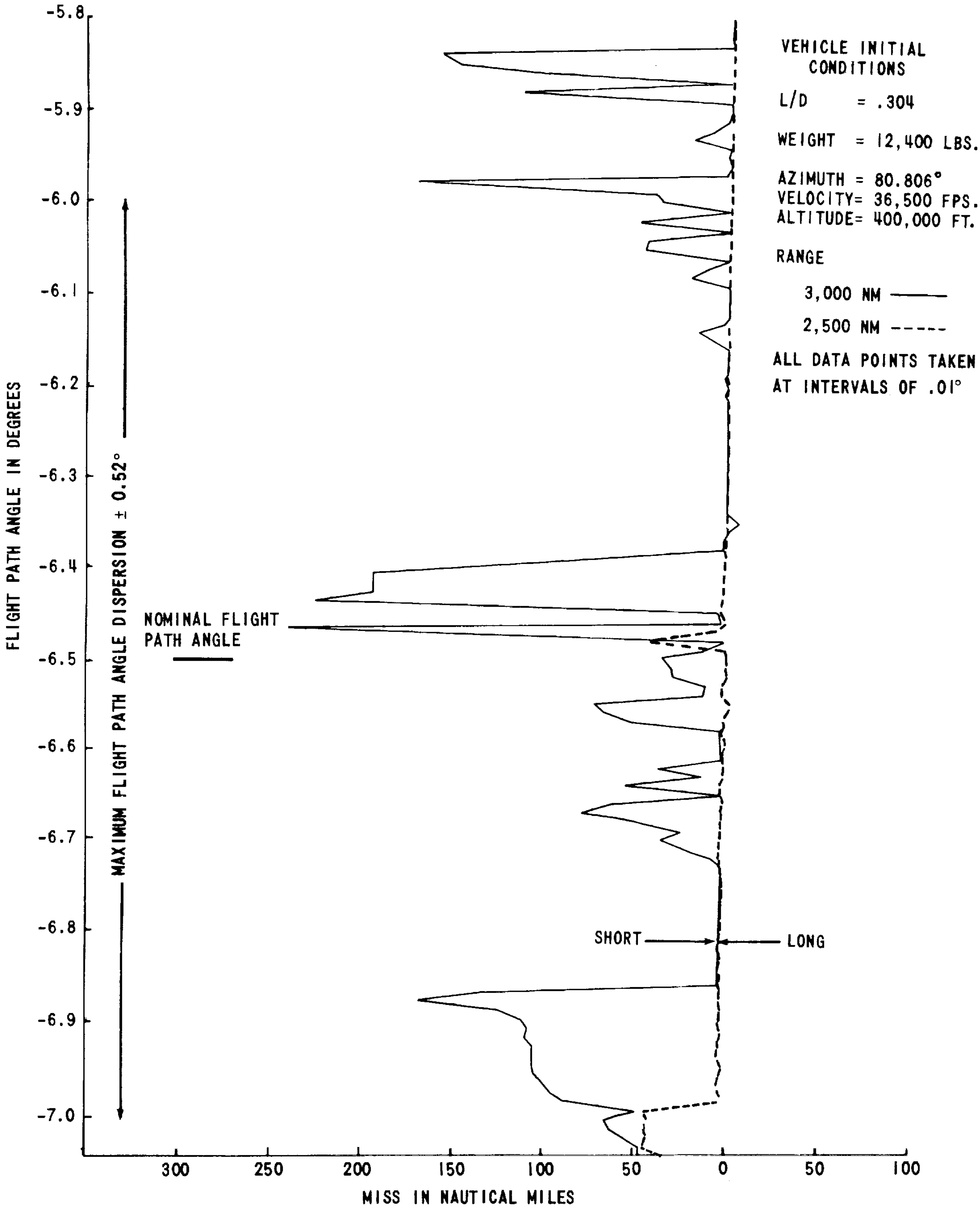


FIGURE 1 - FLIGHT PATH ANGLE EFFECTS ON GUIDANCE OPERATION

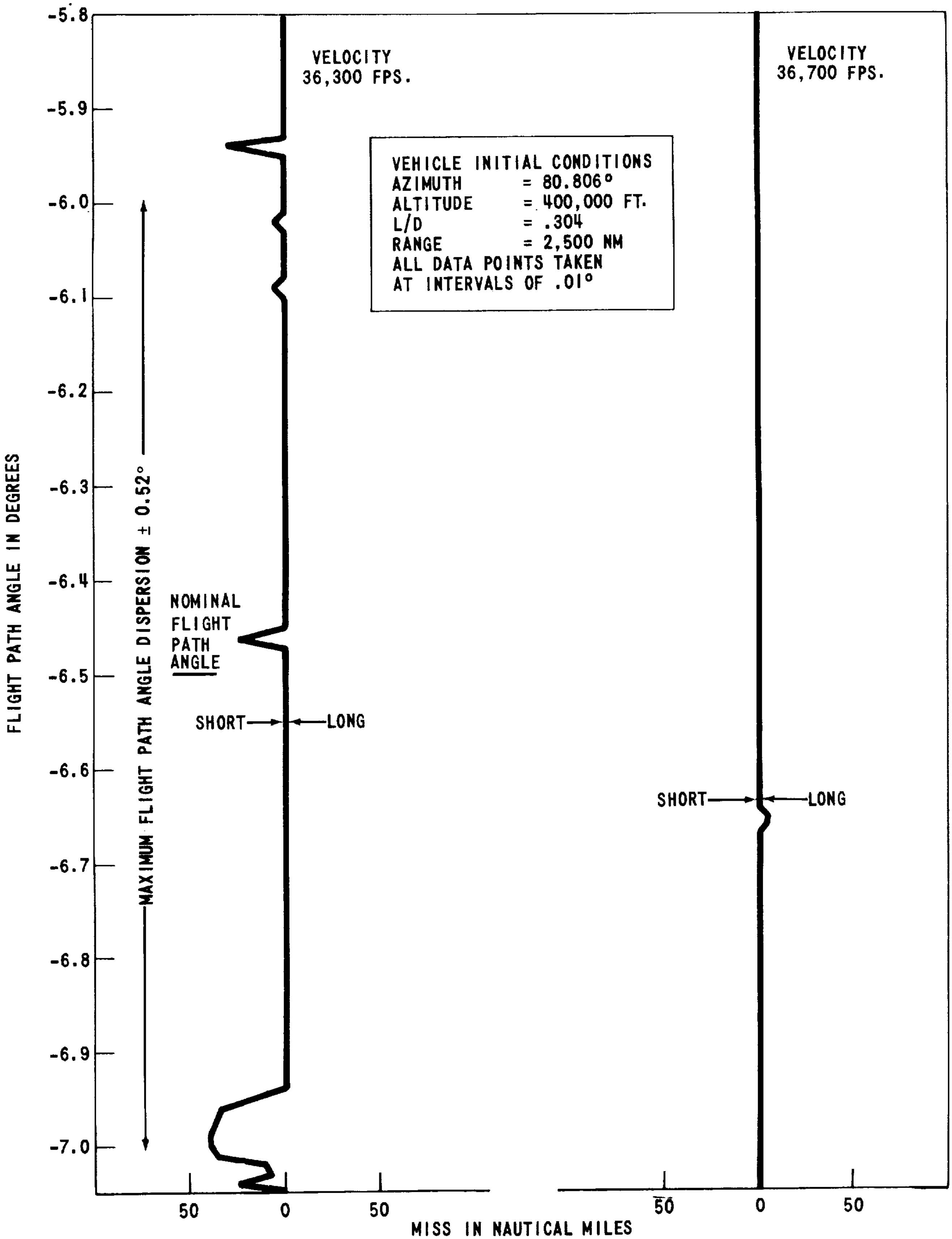


FIGURE 2 - VARIATION OF INITIAL FLIGHT PATH ANGLE ON TERMINAL MISS FOR TWO VELOCITIES

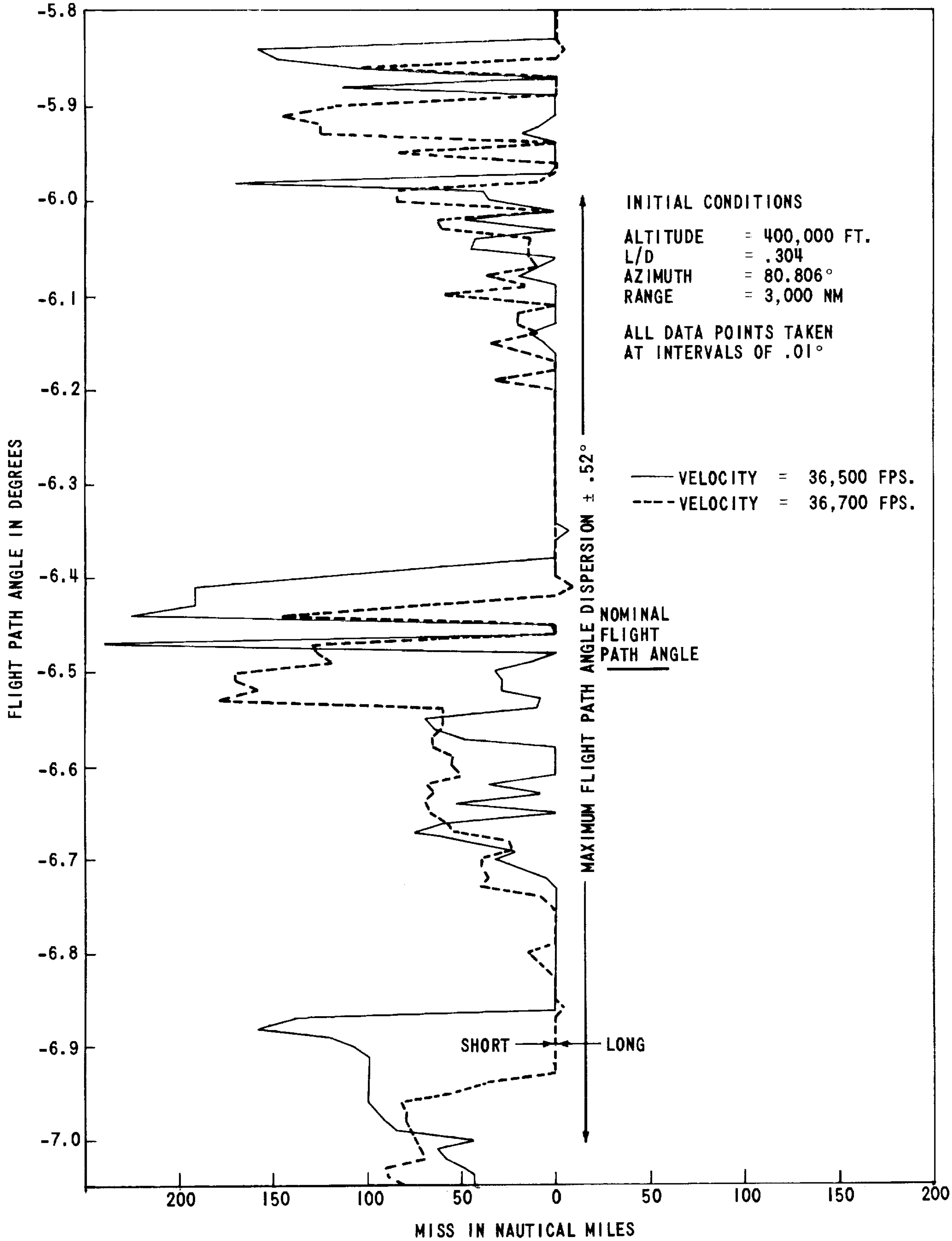


FIGURE 3 - VARIATION OF INITIAL FLIGHT PATH ANGLE ON TERMINAL MISS

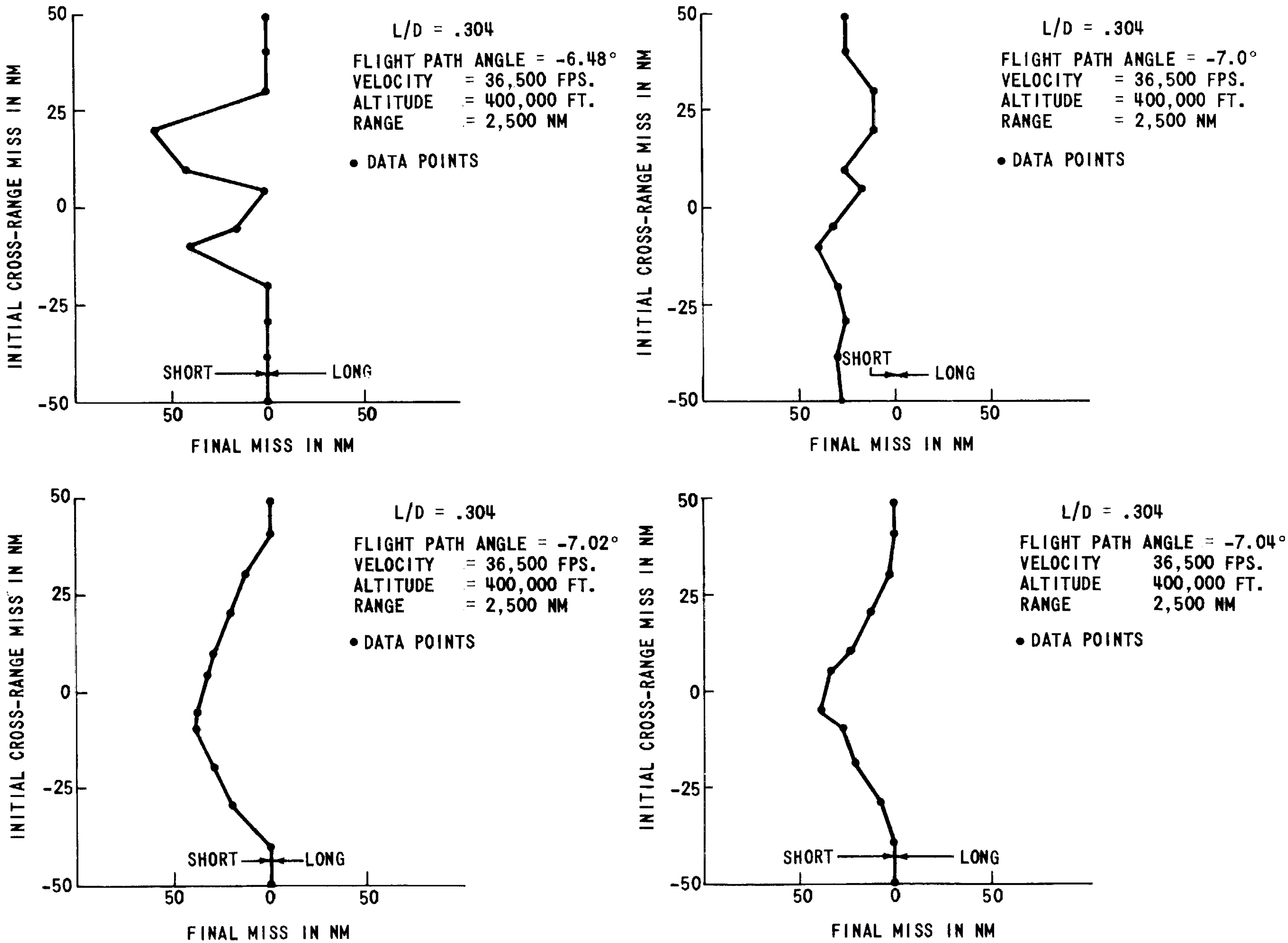


FIGURE 4 - EFFECTS OF VARIATION IN INITIAL CROSS-RANGE MISS (INITIAL AZIMUTH) ON FINAL MISS

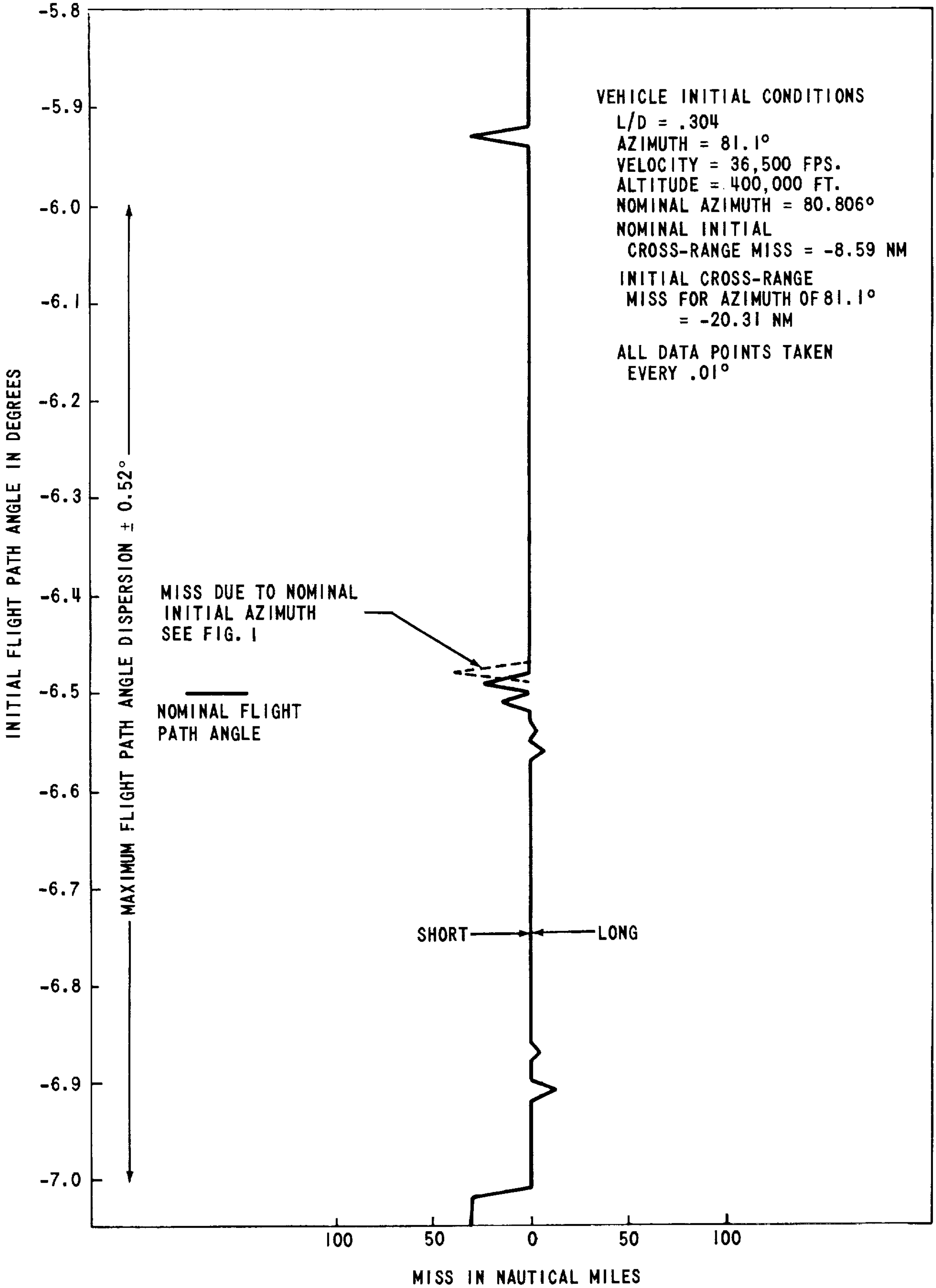


FIGURE 5 - VARIATION OF INITIAL FLIGHT PATH ANGLE ON TERMINAL MISS

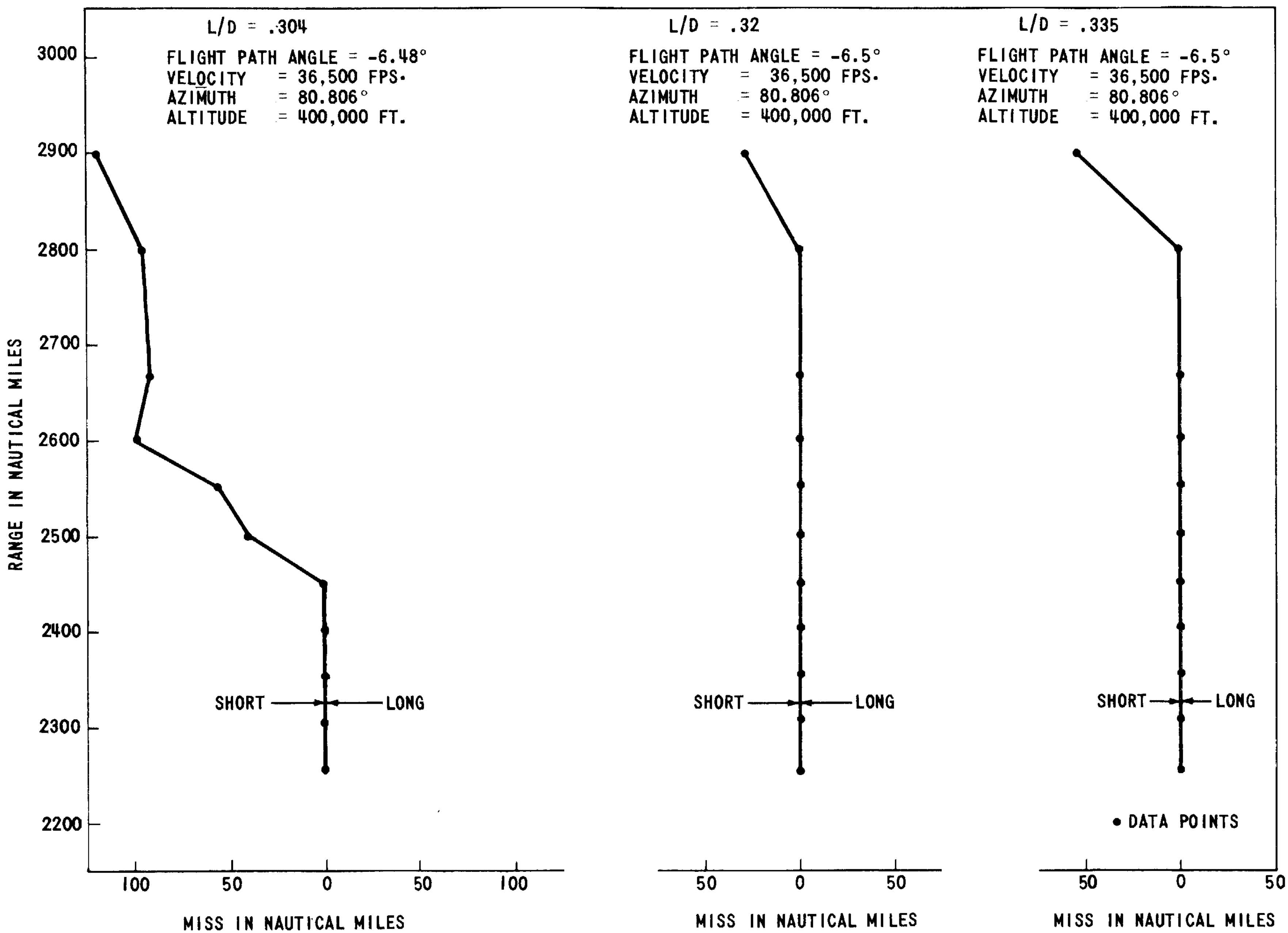


FIGURE 6 - EFFECTS OF RANGE ON TERMINAL MISS

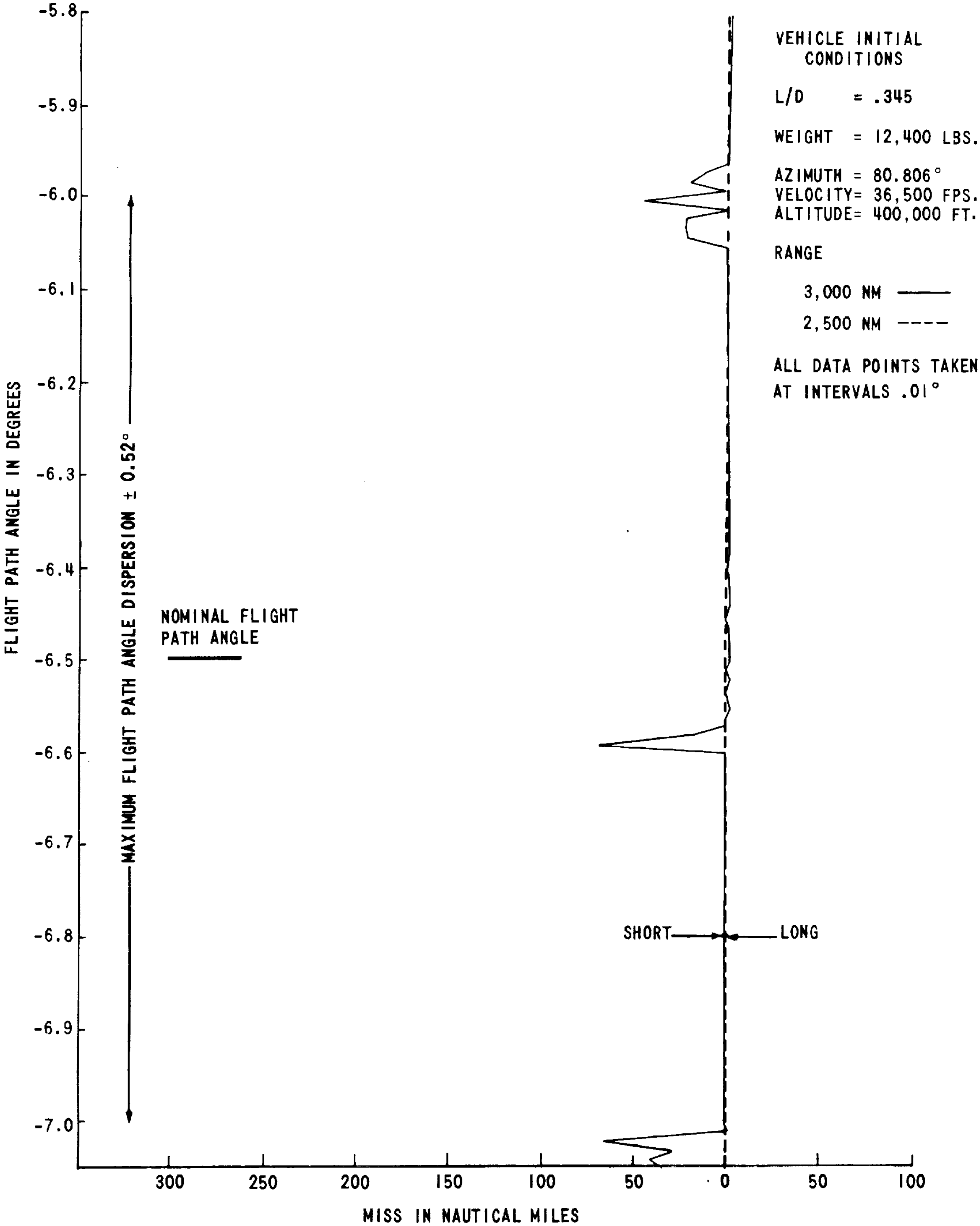


FIGURE 7 - FLIGHT PATH ANGLE EFFECTS ON GUIDANCE OPERATION

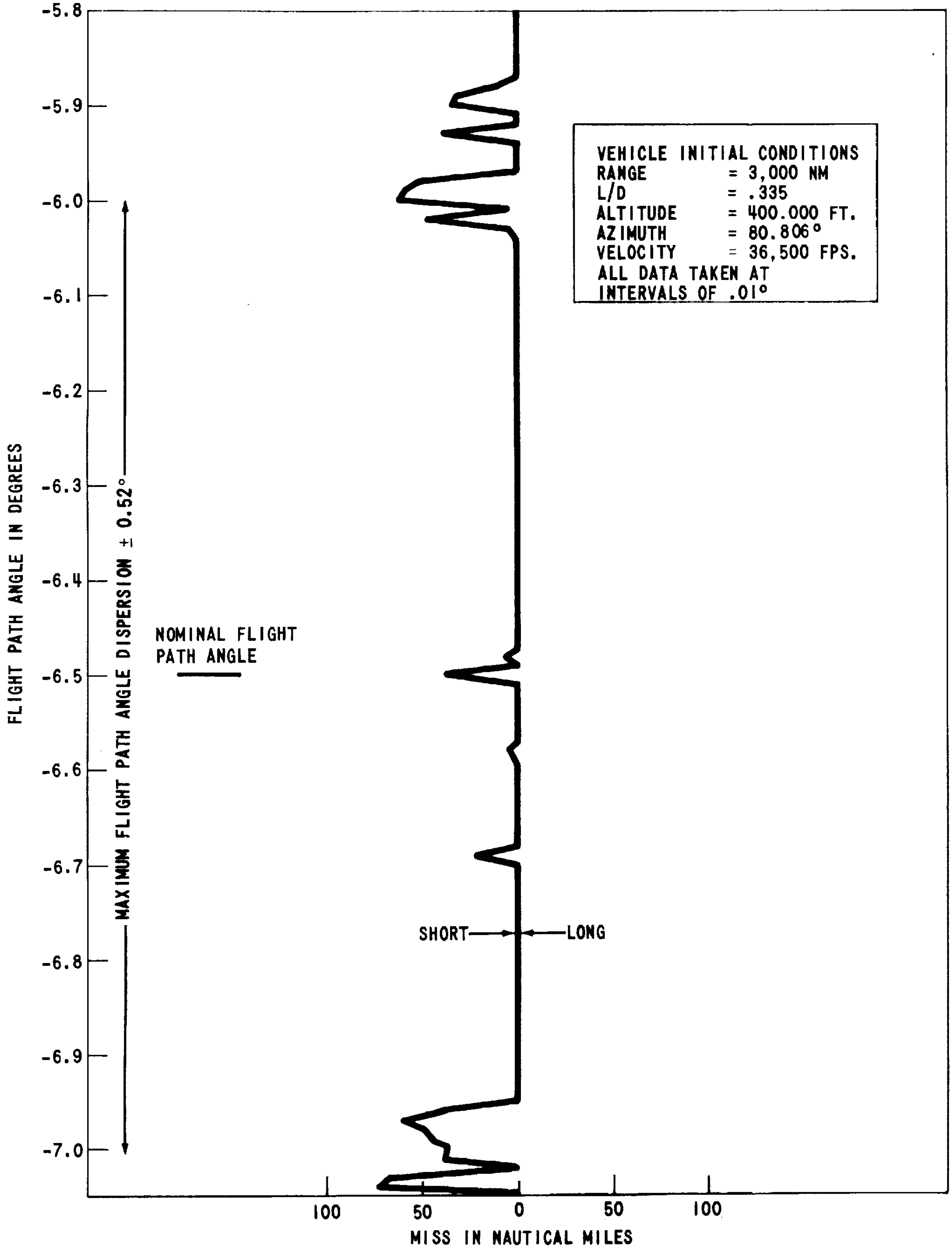


FIGURE 8 - VARIATION OF FLIGHT PATH ANGLE ON TERMINAL MISS

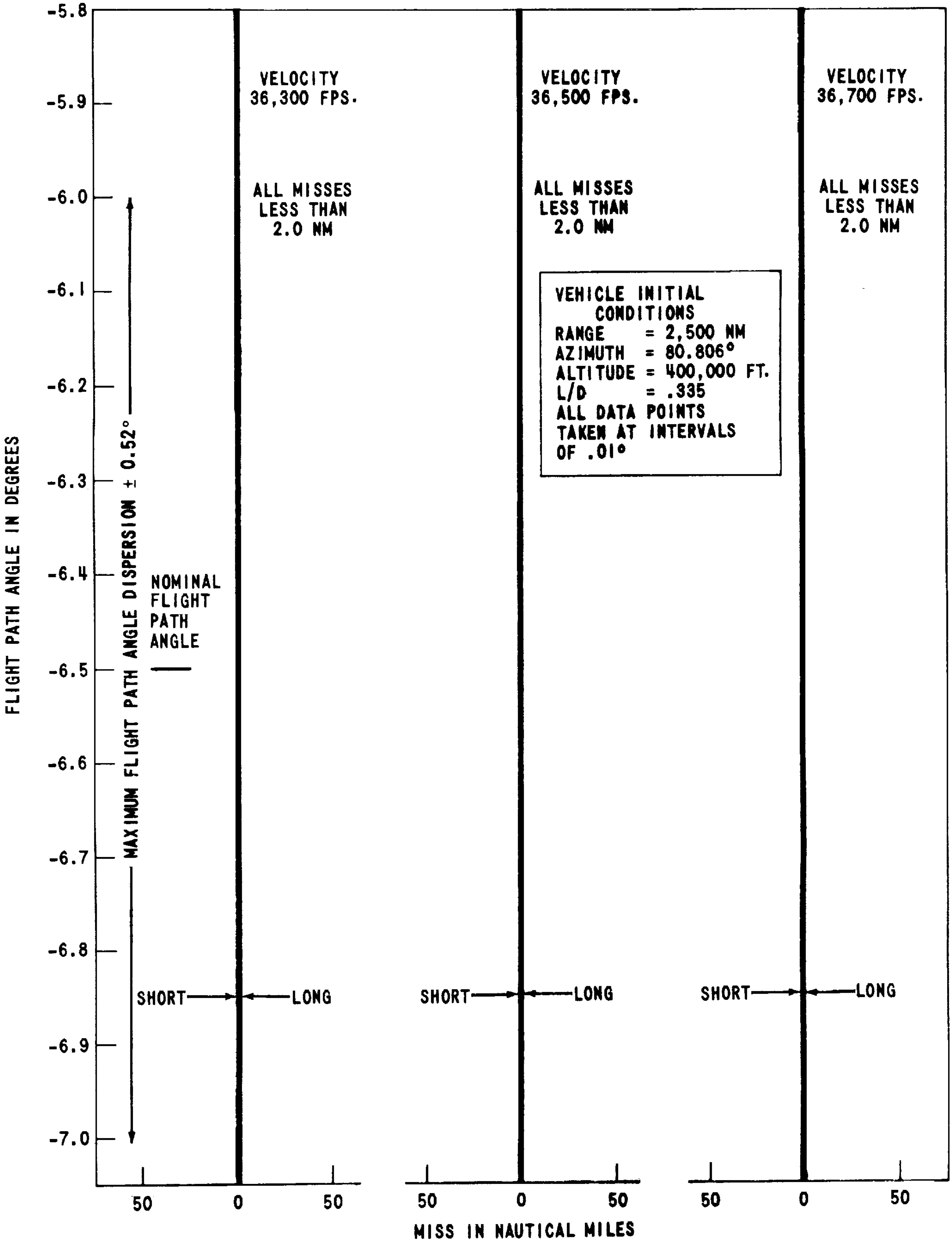


FIGURE 9 - VARIATION OF INITIAL FLIGHT PATH ANGLE ON TERMINAL MISS FOR THREE VELOCITIES

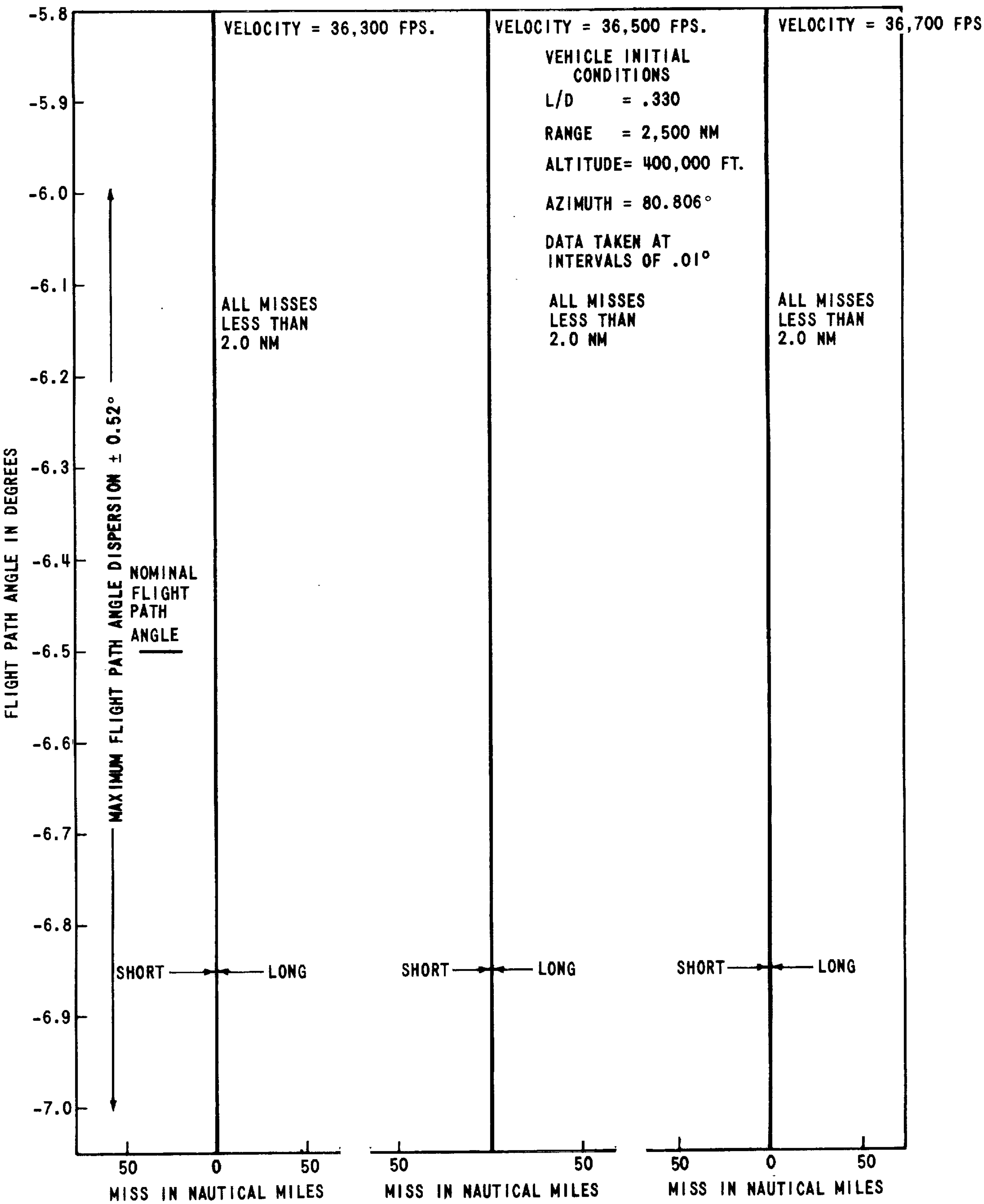


FIGURE 10 - VARIATION OF FLIGHT PATH ANGLE ON TERMINAL MISS

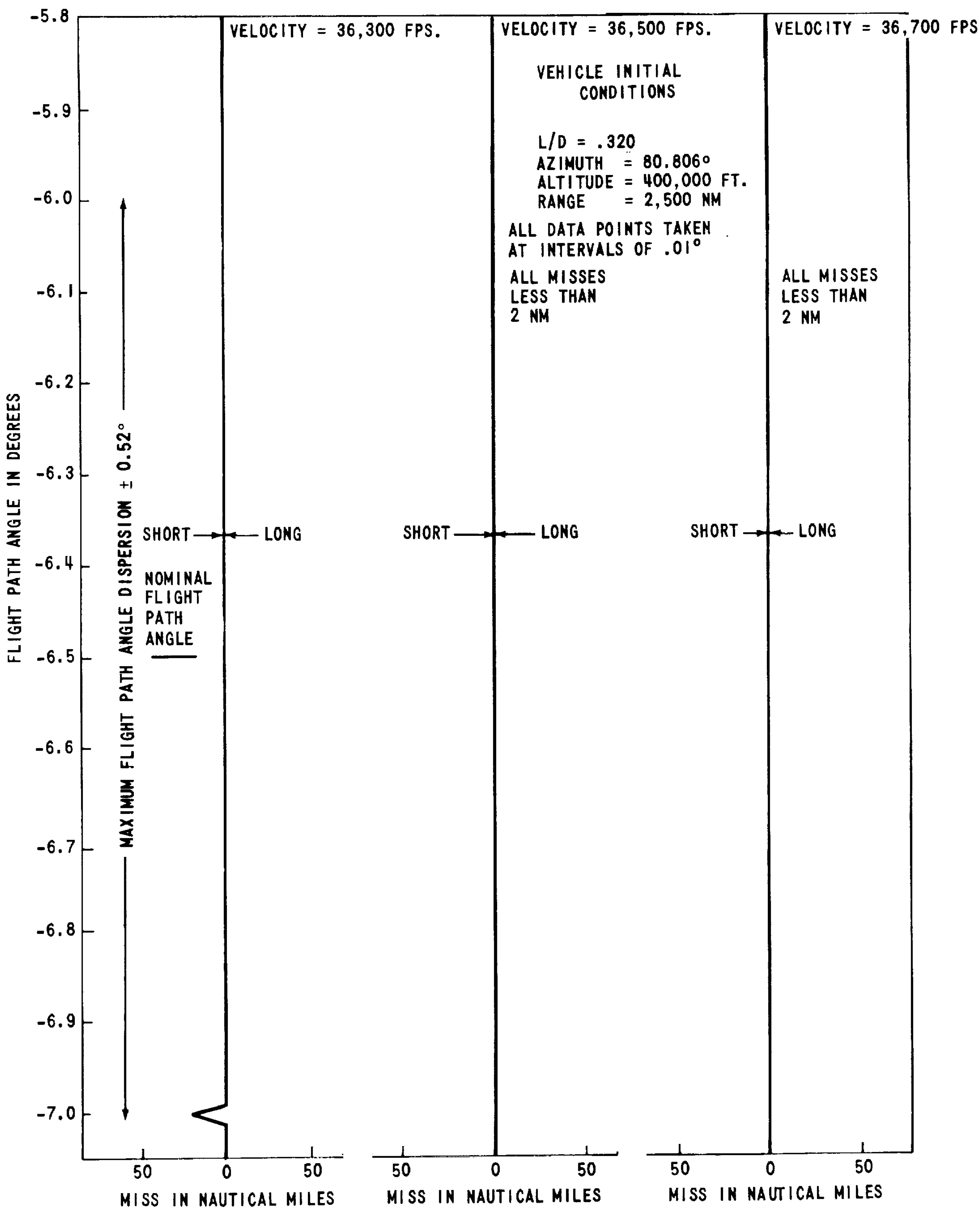
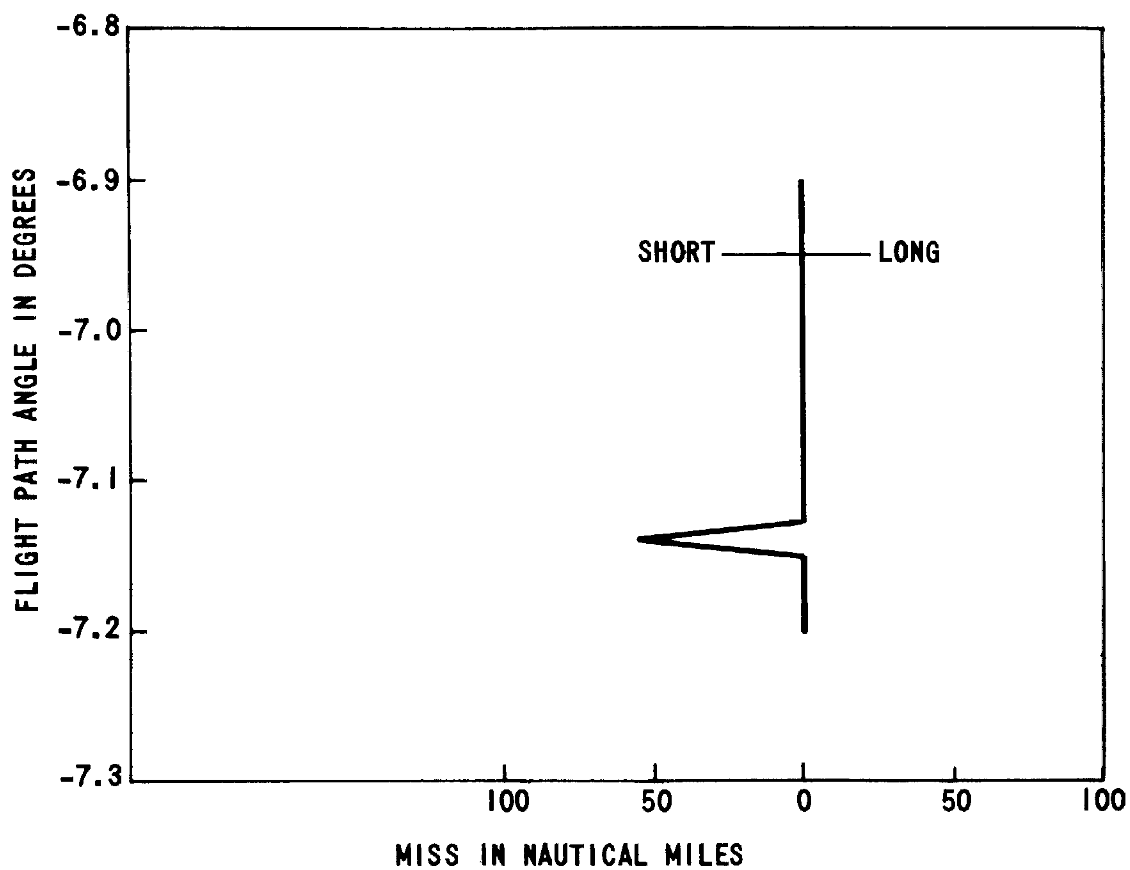


FIGURE 11- EFFECTS OF FLIGHT PATH ANGLE ON TERMINAL MISS



VEHICLE INITIAL CONDITIONS

L/D = .34

VELOCITY = 36,333 FPS.
AZIMUTH = 80.806°
ALTITUDE = 400,000 FT.
RANGE = 2,500 NM

ALL DATA POINTS TAKEN
AT INTERVALS OF .01°

FIGURE 12 - EFFECTS OF FLIGHT PATH ANGLE ON TERMINAL MISS